Analysis of an Open-Source Recycler

The 3DBear Recycler: Origins, the MkI recycler vs the MkII, and how new versions can have the greatest global impact.

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Abstract:
Waste accumulation is a global problem, in order to address it the economic and cultural contributions in a shifting economy must be considered; additionally modular open-source devices like the 3DBear recycler offer a possible scalable solution. This thesis is a review of the processes that led to the construction of the 3DBear MkI recycler, an analysis of the MkI recycler in comparison to proposed changes for a MkII version, as well as an explanation of the niche such a device would fill and its value locally and globally. The 3DBear recycler is a device designed to make waste plastic into 3Dprintable filament. This thesis is a qualitative assessment in the field of material science and engineering related directly to recycling and sustainability. The aim of this study is to both concisely document the current build of the recycler and its history, and to outline next steps and value for the continuation of the project through the proposed revisions and later iterations. It is meant to outline the value of the project in a way that is academically relevant; additionally it is meant to demonstrate this value in settings urban and rural, developed and third world. The current build is broken down and explained on a system by system basis, not as instruction to build the device, but as a breakdown that explains the function and interconnection of the systems. Then the proposed changes are described, again on a system by system basis, providing specific reasoning and rationale for each change. The proposed updates make the MkII device significantly more valuable in part because it becomes less expensive to build, and in part through simplification. By ensuring that the device is well documented and referenced its open-source value will increase as its exposure is increased, and further versions and applications will flow from this same exposure as different groups build and work with MkII or later 3DBear recyclers.

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TABLE OF CONTENTS

FOREWORD

Globally scaled problems like resource scarcity, or oceanic plastic accumulation appear to be insurmountable to individuals, communities, and even nations. In addressing them it is vital to consider their contributing factors and conditions with respect to the changing economies of the world. In order to combat these contributing factors devices like the 3DBear recycler provide an open-source modular possibility that may be well suited to enabling changes in the localities where they are implemented. Additionally they may change the way we look at global problems as individuals, communities and even nations. This thesis examines the potential impact of an open-source recycling extruder designed to make waste plastic into usable 3Dprinting filament. Such a device was built by Paul Nix and Jan-Peter Holm in a student led collaboration between Arcada University of Applied Sciences and 3DBear, an educational technology startup, during 2017. The project was separate from this thesis, but was always meant as a potential springboard for it. This thesis will review key systems of the recycler as they stand now in the MkI design and outline potential changes that might improve the device in the upcoming MkII design which will be made in the future, and will streamline and improve the open-source device. It will also outline the general use, capacity, and community application of the open source recycler as it may be utilized in both a fully developed setting, such as a community in Helsinki, or in a more rural environment such as Keliki on the island of Bali. This will tie the thesis into another previously completed project from 2015-2016 in which the accumulation rates of different plastics were analyzed in order to better clarify the problem of polymer accumulation in a village environment, in the hopes that a scalable solution could be designed to help solve it.

Ideally this thesis will add to the resources academic institutions reference in order to further scientific advancement, while also furthering the maker-movement through distribution of all of the designs, codes, and open-source files housed by 3DBear at www.3Dbear.io/Recycler (3DBear, 2018).

1 INTRODUCTION

1.1 Background - Synopsis of Previous Work

This analysis of the MkI open-source recycler and comparison to proposed design changes in the MkII is only possible because of a string of successful projects and initiatives. This section of the thesis will review preliminary work that led into the MkI design as it is currently constructed in the Arcada production lab.

1.1.1 Bali Ecological Project

In the countryside, in Bali, toward the center of the island, just north of Ubud, is the village of Keliki. During a visit to this village during a break early in my degree program a conversation with a close friend of my family, a resident of the village named Dewa led to the start of an environmental project. We were visiting a cremation ceremony unique to the island; although to an outsider it might seem more like a community picnic due to its celebratory atmosphere, it is a key component of Balinese tradition. Dewa asked me about my studies. I told him I was in a mechanical engineering program focused on plastics technology. He paused and bent to the ground to pick up a piece of plastic rubbish, he held it out in front of me. He said “What can be done about this?”

Figure 1 Paul left, Dewa right, both happy to see an old friend, in traditional Balinese Udang hats. Photo by Paul Nix.

There was no easy answer, my studies into engineering and material science only made it clear how much more difficult a question it was than it seemed. It had been a decade since the last time I had been to Bali and there was now a significant amount of noticeable trash and plastic waste on what was once such a pristine island. Dewa told me they had collected the plastic before but that there was nothing they could do with it when they had it all in one place, there is no infrastructure on the island equipped to deal with polymer accumulation. Plenty of tourists come through and have the urge to "save simple people from themselves" but when these tourists go home the problems faced by locals are sometimes compounded by the attempted solutions. If a solution was to be found it could not be allowed to make things worse than they already were, or make life more complicated or dangerous for residents.

So the seed of the Bali project had been planted. After asking Valeria Poliakova and other Arcada staff members for advice and direction we started planning an ecological project. The purpose of the Bali project was to collect data on the accumulation rates of different types of plastic in a village setting. Arcada staff helped in the drafting of a project proposal, funding acquisition, project planning, and equipment acquisition; without the resources and time that the staff at Arcada provided this project would not have begun.

Once on the island the people of Keliki showed tremendous support for the project, in particular Dewa and his family were integral to its success.
In practice the project started with recruiting volunteer households; the participating families were instructed to collect anything they would normally throw away, with the exception of biological waste, into a provided bag, for a set period of time. Once collected, along with data about the household and number of family members, the waste was labelled, weighed, and relocated to the sorting location. Waste was sorted with help from volunteers, into categories by type and each sorted pile was weighed by category. Representative photos were taken of waste during the process. All the data collected was later analyzed and put into a project report.
It was hoped that once the scale of the problem was determined, a new project could begin that would produce a solution to Keliki's waste accumulation that would be safe, simple, scalable, modular, and open-source. In simple terms it would have to solve more problems than it had the potential to create.

1.1.2 Recycler Prototype Tampere

Students at a University in Tampere developed an extruding device to support their large-scale custom 3Dprinter, primarily it was made to process PLA (polylactic acid) plastic into filament. It was assembled primarily from parts that were in their lab space as leftovers from other projects. Some of these parts were shockingly overpowered for this application, and others were custom made on-site using significant custom machining time and material, and others were put together on an as needed basis. The prototype device had a much more powerful motor than the 3DBear MkI recycler, additionally it had a much larger footprint. The screw and barrel were nearly twice as big, and because of this the filament extruded much more quickly and remained hot longer, necessitating a cooling bath. This initial prototype caught the attention of 3DBear who bought the rights to the design and concept.

1.1.3 3DBear Recycler MkI

3DBear hired Jan-Peter Holm and I to review the existing prototype and to design and build a new device. They had heard about us because we had both had several projects in the Arcada production lab including my Bali project and several hardware projects that Jan-Peter had completed. Kristo Lehtonen, one of 3DBears founders and its CEO, made it clear from the very beginning that 3DBear was concerned about long-term sustainability, and that the entire project would be made open-source upon the completion of the MkI device. Their goal was to help ease the way for 3Dprinting technology that is being adopted very quickly worldwide, so that infrastructure demands could keep up, and people would learn more sustainable practices. Kristo was also very concerned about the rate of plastic accumulation in our oceans and felt that projects like this were a responsible way for businesses to do their part.

Jan-Peter and I quickly set to work to see what it would take to replicate the specifications of the existing device. We outlined our expectations, we wanted a system that would outperform similar DIY and for-purchase extruders, producing filament of a higher quality faster and at a material cost that was well below the price point set by any competing products. As it stood replicating the prototype directly would have been far too costly, so we went about reducing the size of the screw, barrel, and motor, as well as the overall footprint.

We led the 3DBear recycler project ourselves with the full support of both 3DBear team members and the Arcada university staff. The project agreement allowed for the full use of the Arcada plastics lab, parts and components were to be purchased by 3DBear. We decided that the recycler should lend itself as much as possible to open-source and modular parts, so many of the components were designed to be 3Dprinted from the very beginning. Work was collaborated between Jan-Peter and myself, the two of us coming together for regular consultation on designs and difficulties and systems being divided up between us for day to day efforts. Regular progress reports were brought back to 3DBear, generally on a weekly basis, where we would present pictures and video of significant advances. As planned upon completion of the MkI, the design, all components, and source code were made open-source and shared online at www.3DBear.io/recycler.

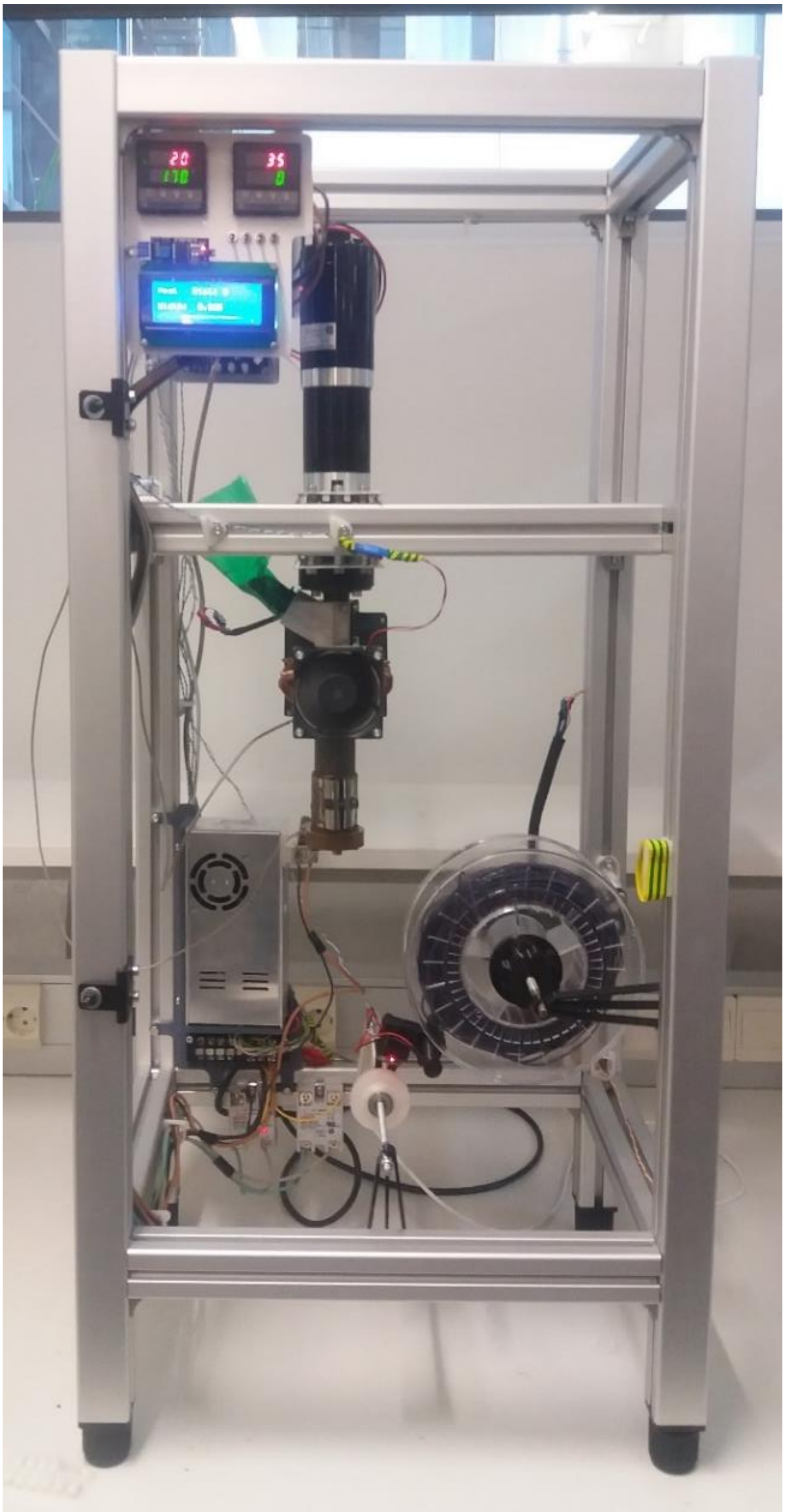

Figure 2 The 3DBear Open-Source recycler MkI. Photo by Paul Nix.

1.2 Objectives - Changing Global Economy/Developing Circular Economy

The 3DBear recycler and open-source devices like it are making changes, but the world is changing with or without them. Consumers are becoming more aware of the impact made by the products they use and services they purchase, so that terms like carbon footprint which only came into common use in 2007 have become the basis of many business models, city plans, and even global legislation like the Kyoto protocol. (Nations, 2017) This section breaks down a look at the overall changing economy, (Ellen MacArthur Foundation , 2018) the causes of it, and possibilities for the future that are opened up by it.

1.2.1 Digitization of Products

The age of computation has changed the way we interact with our world. When computers began to be able to store information we started digitizing text, users began to be able to enter their own text directly into a digital format changing the world of writing and communications. As time went on we began to digitize pictures and music, then video. As these changes have occurred related industries have been transformed. Now we are able to digitize products, and more and more people will be able to digitally redesign the objects that will exist around them. Coupled with 3Dprinting and other forms of rapid prototyping the product logistics chains that have defined our global industry for generations will change as well (Bruce-Lockhart, 2015).

1.2.2 Localization of Production

Communities will be able to bring production back to a localized and an at need basis. This means that consumers will be closer to the resource use that leads to their finished products. For example an IKEA Sötcitron self-watering pot designed by Maria Bergström, costs approximately 6.99€ or $9.99 US, it has to be shipped from wherever it is manufactured and shopped for at your nearest IKEA (IKEA, 2018). An equivalent, customizable, free to print, self-watering pot designed by Parallel Goods is available from www.cults3d.com. (Cults 3D, 2017) One is customizable, prints in your choice of color, in a few hours, and from the material of your choice, for less than 1€ of material.

Figure 3 IKEA Sötcitron left, Cults3D/Parallel Goods right. Photo credits to IKEA (IKEA, 2018) and Parallel Goods (Cults 3D, 2017).

Modular storage, household gadgets, emergency tools, even modular furniture is not out of the reach of a standard 3D printer. A vast amount of the specialty products that once required specialized tooling and factory grade design knowledge are available to print in our garages or libraries for a fraction of the cost. In fact many of these devices are less than a minute away through a google search, the following examples are all from one list hosted by www.all3Dp.com. (Yusuf, 2017)

Figure 4 Simple freely available 3Dprintable project examples, battery storage left, headphone keeper right. Photo credits Thingiverse (Thingiverse, 2018).

Figure 5 More free 3Dprintable examples, an emergency whistle left, a modular chair right. Photo credits Thingiverse (Thingiverse, 2018) and Youmagazine (Youmagine, 2018).

1.2.3 Resource Utilization

Now the focus will shift from buying products to buying raw material, then the focus will move toward resource management. When one of the joints of a 3Dprinted/plywood chair breaks what can one do? Simply 3Dprint a replacement component, the chair is whole again with no problem, but that broken component can be put into a shredder and recycled into new printable filament stock. That is a small part of what the recycler is for. Failed prints, old and broken prints, support material, all of it is useful and more people will see an immediate value for it when they can take a grocery bag full of plastic down to a local filament producer, or their school, or library, and get a new spool in exchange. This section addresses the role of devices like the recycler in changing the way people treat resources as our societies change.

1.2.4 Modular Answers to Global Problems

As people reconsider the definition of the word waste and the production economy shifts back to the local level, people will begin to consider new methods of tackling the big problems that face us. Problems that exist at a global scale require systemic shifts in behavior in order to produce changes at a societal level. We do not have a clear path to designing solutions at this scale; however, the optimum starting point is generally study of the problem and a study of its scale and contributing factors.

Climate change, is a potentially overwhelming problem that may completely shift ecosystems and lead to the decline of countless species. There is overwhelming evidence pointing to current observable change being linked to recent human activity. In fact one can use NASA's website to track live changes in key metrics linked to global climate change. For example the amount of measured carbon dioxide in the atmosphere, which measured 381.11ppm 12 years ago in 2016, can now be registered at 407.22ppm having made steady gains during the intervening years leading to 2018. The average global temperature, is registered there and can be shown to have risen dramatically from 1975 on. Similar metrics, like the amount of observable ice on the land and sea reducing dramatically as the ocean levels have risen, can be followed as well. (NASA, 2018)

Along with changes to ocean levels, plastic accumulation in the oceans has reached a point where masses of floating polymer waste can be identified having clumped together into floating islands called gyres pushed by ocean currents. Each of these massive oceanic gyres of plastic are, according to the most conservative estimates, 700,000 square kilometers, which is roughly the size of Texas. Five major gyres have been identified. Over time these masses of waste begin to break down into microplastics that soak up and accumulate persistent organic pollutants or POPs and are ingested by ocean life and begin to bioaccumulate as they pass through the food chain (Takada, 2013). This means that as smaller ocean creatures eat bits of plastic, they are eaten by larger creatures, which are in turn eaten by larger creatures; at each step the amount of plastic that is collected rises. Consider an example where krill each eat 10 particles of microplastic, and small fish each eat 10 krill, and larger fish each eat 10 small fish, finally a shark eats 10 large fish. If each particle of microplastic weighed 0.2 grams the following math would get you average accumulation across these four trophic levels:

$$0.2g * 10 * 10 * 10 * 10 = 2{,}000g = 2kg$$

Not so bad if you have a large shark, but consider instead that between the krill and shark there are 4 four different sizes of fish instead of two.

$$0.2g * 10 * 10 * 10 * 10 * 10 * 10 = 200{,}000g = 200kg$$

Now consider that the top level fish is not a shark, but is instead an Atlantic Bluefin tuna. For the sake of argument let's say that only 10% of the microplastic has made it into the tissues of this 3 meter long 450 kilogram animal. How much microplastic is entering human diets when the tuna is caught?

$$200kg * 0.1 = 20kg$$

Of course this is a drastic oversimplification. Finding solutions that protect us and the ecology that we live on is a titanic task, even if you address each ecological problem individually they are overwhelming. If solutions are worked at by entire populations in coordination options become possible. By coordinating efforts and sharing data we open the doors to modular solutions and development. These problems, like the overuse of natural resources for example, seem massive because people don't feel empowered to start dealing with them. Once people start to work as larger communities understanding of these problems will be much more accessible, solutions comprised of smaller modular units will not only make sense, they will be simpler to implement.

1.3 The 3DBear Recycler in a Community

The 3DBear recycler has the potential to change the infrastructure feeding our DIY, educational, and maker communities. It has the potential to vastly change physical communities as well by interconnecting different facilities and localizing the production of useful materials and the processing of waste, while also facilitating other local solutions.

1.3.1 General

The 3DBear recycler project is designed to allow anyone in the world to produce a machine that can reprocess waste into a useable resource. The digitization of objects and localization of production will make devices like the 3DBear recycler extremely useful to communities of all kinds. Most importantly the fact that a device like this could support many different 3Dprinters means that while it would require slightly more technical know-how to assemble, the same students or makers who build a MkII or later revision would have the technical experience needed to help build, repair, and maintain 3Dprinters in their immediate community. This creates multiple links joining parts of the community that might not have otherwise interacted, and encourages shared resources.

Libraries, schools, and recreational centers with 3Dprinters could collect their waste plastic for recycling. The facility that built the recycler can coordinate with these printer locations supplying them recycled material while acting as a hub that allows them to pool resources. Finally the recyclers can act as a technical resource giving 3Dprinting guidance, repair, and support to more casual makers.

1.3.2 Urban

Modern city-centers are an excellent location for material recyclers as they will allow communities to be more aware of their resource consumption. Modern civilization has taken a turn since the 1950's away from shared community resources towards the model perfected in the 90's where a person can go for weeks without seeing any neighbors. Actively promoting the circular economy by localizing modular recycling infrastructure could build connections between local businesses and community members. It could even alleviate the isolation that leads to high rates of depression in modern urban communities. Ideally in the same way that community gardens and other resource sharing programs have been beneficial to urban and metropolitan areas, the 3DBear recycler will help to bring value to community centers that bring people together. In this way a hobbyist who has built her own 3Dprinter and relies almost entirely on online resources could theoretically benefit from and help to construct a device she could not necessarily afford on her own while making connections in her immediate environment with community members who would perceive value in her, bringing her business, and who might be able to offer her value in exchange. Similarly members of the community with limited technical training or expertise would be able to apply their varied skills and backgrounds to projects tied to 3Ddesign and printing simply because printers in their local community centers were available, well-supplied, and in proper repair.

1.3.3 Rural

Rural areas and the third world have an incredible opportunity to reclaim a missing degree of autonomy. In many parts of the world, like the village of Keliki in Bali, the infrastructure that is required to prevent plastics from entering the environment does not exist. While in the Nordics it may even be taken for granted that when you have rubbish you can put it into a conveniently located bin for collection and disposal at an energy waste facility that reclaims the plastic as cleanly burned fuel, much of the world still relies on poorly regulated landfills, or just as often local dumping of waste into waterways where plastic is swept into the sea.

Small communities in rural regions could suddenly deal with problem waste in a way that provides immediate resources. In fact by coordinating community resources, collection points, and storage could be allocated for more waste than just PLA. Ideally a local school could build the recycler, and coordinate with others online to know the best ways to blend or use different recyclable plastics like high density polyethylene (HDPE), polypropylene (PP), or even polyethylene terapthalate (PET). While the recycling process may seem as simple as collecting plastic, cleaning it, sorting it, and melting it, some plastics require more work to safely and effectively use them in an application like 3Dprinting. For example PVC (polyvinylchloride), which is commonly marked with recycling code 3 (Ciotti & Sevenster, 2013), can release chlorine compounds when melted or burned, and should be collected for sale as a bulk resource to a facility that can process it safely. PET, recycling number 1 (Tracy Zhou, 2009), can be recycled but will absorb moisture from the atmosphere, so if it will be used in any precise 3Dprinting it will need to be dried and stored in a dry environment, otherwise it will extrude badly as water boils out of the hot end during printing. Finally HDPE has a low melting point of approximately 110°C, and can have difficulty adhering to other materials while molten.

Rural areas would have the most to gain from basic material education which could include well documented references for quick answers. They would be able to build their own infrastructure to deal with waste safely, and some of the collected and sorted plastic could even have a greater value for resale if stored in bulk. There is currently a Balinese smartphone app that coordinates material buyers and sellers used to get people the best prices on collected plastics. Changing the mindset from waste to resource immediately started to make a difference in how a community could organize.

1.3.4 Education

Communities benefit when they have access to more resources. Nations benefit when they start to take ownership of their contribution to global problems and collaborate to solve them at the local level. People benefit when they save time and energy by modeling and producing custom solutions that reduce their need to waste. Education is at the core of all of these benefits, access to simple and clear material science, access to open-source designs and globally accessible e-resources, and access to tools and training centered around 3Ddesign, 3Dprinting, and programming which can let everyone start using the latest technology immediately can drastically change the world.

The benefit of building a recycler to educational institutions is twofold. First they have an immediate connection to other local groups in their communities, and can more easily coordinate events and initiatives of their choice. Second they can coordinate their testing and experimentation with sister-institutes around the world reducing their workload and vastly increasing their access to relevant data.

Educational resources that focus on 3Ddesign and thought processes, like the 3DBear augmented reality (AR) app make design education available on a smartphone (3DBear, 2018). Course material and content that make that app useable to meet curriculum guidelines for children as young as 8 years old ensure that the next generation will grow up with a firm understanding of how to practically engage using modern techniques. All of this continues to support an economy in which localized fabrication is a fact of life.

2 LITERATURE REVIEW

The major criteria used to determine the value and design of the 3DBear recycler were the comparison of price to output quality. This means that the existing options available were either A) expensive and able to produce a fair quality filament as determined by consistency of diameter, or B) less expensive and produced inconsistent filament. In fact most devices that were available were both too expensive, and produced inconsistent quality filament.

This literature review is broken into two major parts. The first is an analysis of existing competing extrusion systems. The second is an analysis of the MkI device on a system by system basis.

2.1 Competing Recyclers

2.1.1 The Filabot EX2 Filament Extruder

Filabot advertises their extruder as a closed loop system for recycling 3Dprinted plastics into filament (Filabot, 2018). They offer their current model the Filabot EX2 for $2,500, it is a simple bare bones table-top extruder that produces a filament horizontally. It does not offer any quality control on the filament aside from the size of the die attached to the devices' hot-end. It is also missing a large scale hopper for material. Effectively, in order to get a 1Kg spool of material, after purchasing this device and setting it up one would have to feed it several times and let it spit out long looping spirals of filament to be spooled manually.

This is an example of a commercially available competitor. The focus of Filabot as seen on their website is clearly to turn a profit. They offer many accessories, and offer a starter kit that includes several other components that would be necessary for filament production. The kit includes the EX2 extruder, a spooling component, and an air suspension/cooling system, for $3,299. However, even in the kit the only controls on the filament diameter are the die, which shapes the extruded hot plastic, and the spooler puller speed.

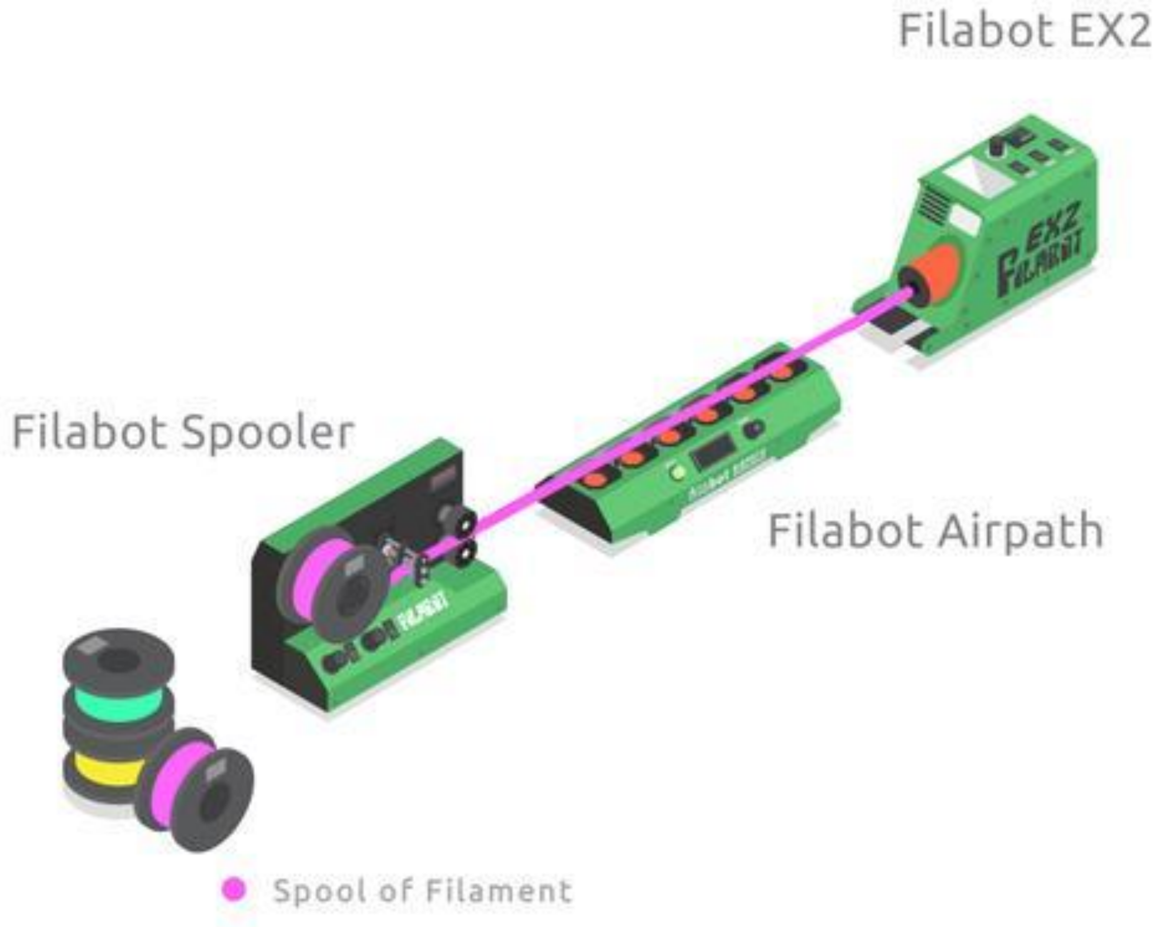

Figure 6 The Filabot Starter Setup Bundle. Image by Filabot (Filabot, 2018).

A company with a 3Dprinting lab might find value in a Filabot system as it is a turnkey solution available for purchase. It is likely that the company would be able to reclaim material with the EX2, but would likely require the EX6 which sells for $9,499. This sort of solution is not viable in a community or DIY setup because of the cost.

2.1.2 The Precious Plastics Extruder

In comparison the Precious Plastics extruder is focused entirely on design simplicity and availability. The designs are made to be easily constructed, but require access to metal-working and machine tools, they are however freely available. The Precious Plastic focus is on a larger environmental impact. They go out of their way to focus on the network of devices that have been built and the suppliers who can produce different related components (Hakkens, 2018). As before the design is initially meant to be a horizontally driven extruder, and in the same way as the Filabot EX2 the only quality control system is the die in the hot end and any externally configured spooling system.

This device is available to anyone and would be simple to construct and repair. It is effectively completely manual. In the expanded information available on the Precious Plastic website, there is a kit upgrade that would allow the device to be wall mounted in a vertical extrusion position. This would allow a greater degree of uniformity in the output, similarly to the Filabot device any filament would have to extrude in long coils on the ground to be manually spooled.

The precious plastics components are not configured for 3Dprintable filaments and would likely cause jams without exceptional oversight. These solutions are designed in order to allow the recycling of bulk plastics and allow for simple injection molding as a means of addressing the larger plastic accumulation problems the world is facing. Precious Plastics does this wonderfully.

Figure 7 The Precious Plastics extruder. Image by Precious Plastics (Hakkens, 2018).

2.1.3 The Lyman Filament Extruder V1-6

A third competing solution is completely focused on the DIY community. The Lyman filament extruders' versions 1-6 have been constructed in order to allow for the community to produce their own filaments (Lyman, 2018). Again the designs are freely available through the Thingiverse website, additionally designs can be found for compatible spooling systems and accessories (Thingiverse, 2018).

The V6 is a vertically driven extrusion system with a large scale hopper. It allows for continuous production of material which can later be cut and spooled as desired. As a solution it is ideal in its simplicity, but still lacks quality control of the filament diameter as do the other solutions. Schools and communities will be able to produce this machine as effectively as the precious plastics model, and will likely get a higher quality device.

2.1.4 Conclusions

These competing recyclers lack in quality control systems that would lead to consistent filament output. Devices available for sale are cost prohibitive, and all devices are incomplete solutions lacking integrated spooling. These devices are made for specific environments, for example the precious plastics device is meant for reasonably low tech workshops dealing with large scale bulk plastics. The Filabot was designed for a company environment with a dedicated engineering staff and 10 or more 3Dprinters where it would work with large supplies of waste coming from production. The Lyman extruder was designed for hobbyists with access to 3Dprinting for the manufacture of several parts, and a more varied input of material.

There is much to be learned from each of these solutions and each was studied in detail and debated during the redesign of the Tampere prototype. It was concluded that a device needed to be open-source, under 1000 euro's in parts, and include both quality control and spooling in the device. The 3DBear recycler is meant for a DIY environment that uses 3Dprinting actively and is central to a community. It is meant to be simple enough to repair and build that anyone who might build their own 3Dprinter could build and operate it. Finally it must provide an immediate solution to the common build-up of old prints, failed prints, and scraps; as well as a long term solution to other accumulated plastics. In this way many different groups whether they were just entering 3Dprinting, or were active veteran enthusiasts would be able to pull aside their waste and see it become a valuable resource.

2.2 Core Systems of the 3DBear MkI Recycler

The 3DBear MkI recycler is comprised of several different active and passive systems. They can be divided and grouped based upon overall function. The systems are detailed below as they are currently configured in the MkI, with further detail based upon the design process that went into each of them.

2.2.1 Logic System

The logic system comprises the logic board and control circuitry used to manage the functionality of the recycler as well as display components and the power supply. The center of the logic system is the logic board, a printed circuit board designed as a mounting point for most of the core components. The logic board houses the Teensy chip which is used as a processor, it acts like an Arduino and is coded in C+ which allows for customization and control of the system. This system can be interfaced and updated through USB interface. During operation the code can be updated live and data can be monitored directly.
The logic board also holds the stepper motor controller which can be configured to regulate the speed of the spool puller. An optical sensor is installed in the recycler and is located near the hot end of the extruder in order to measure filament thickness. The data retrieved by the optical sensor is fed back to the Teensy which maintains the optimum filament thickness by speeding up the spooling puller motor if it detects a filament that is too thick, and slowing it down if it detects a filament that is too thin.
Below the logic board is the larger Phidget motor controller used to regulate the speed of the screw. This system also includes the display board mounted at the front of the recycler, which displays the total length spooled and the live filament thickness. Power for the entire system is regulated by the power supply which feeds a reduced voltage into the logic board and Phidget motor controller. There is also a set of switches wired to the front of the device which can be wired for specific inputs and live controls.

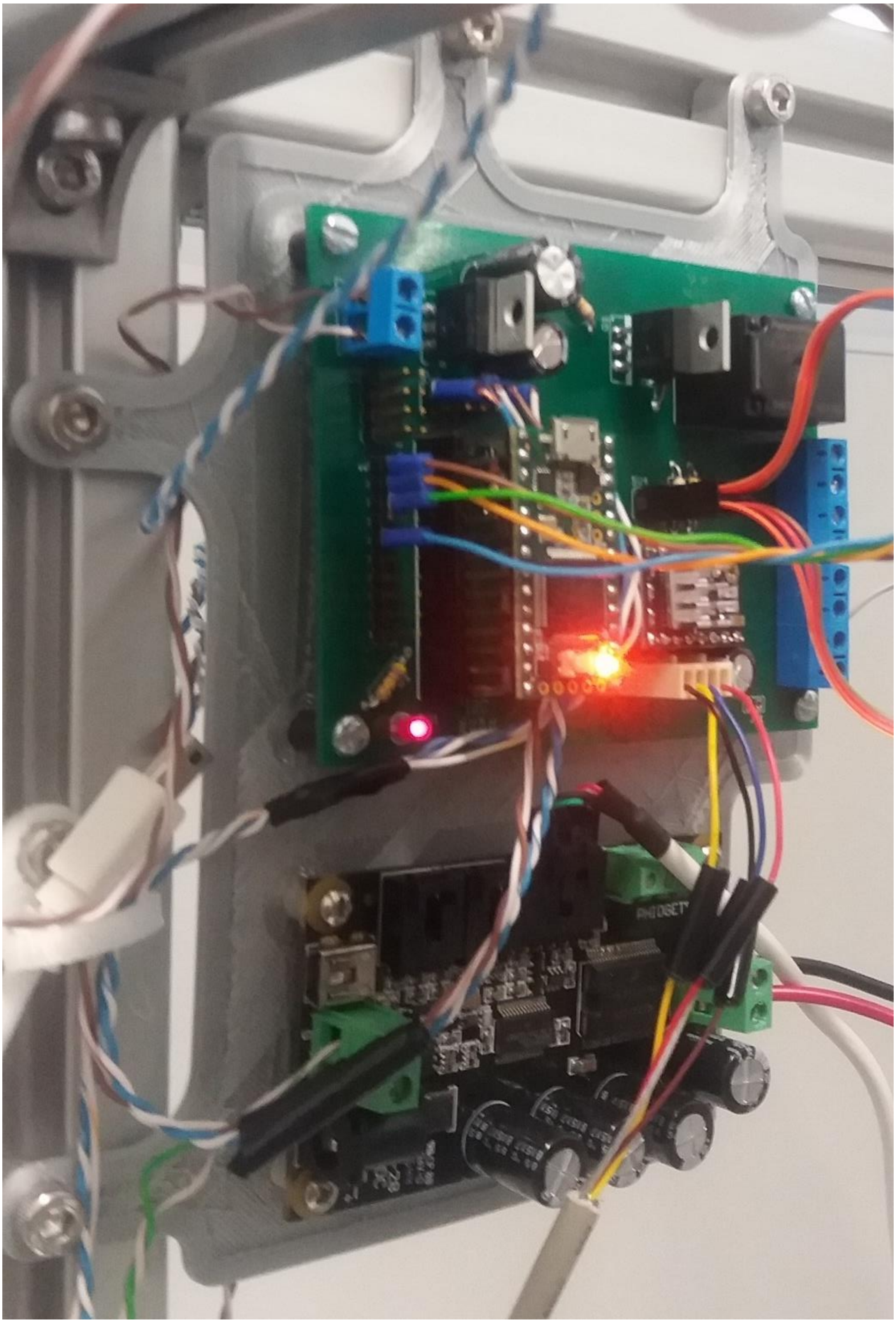

Figure 8 The logic board top, the Teensy has the bright LED, the Phidget is mounted below. Photo by Paul Nix.

2.2.2 Heating System

As it stands in the MkI recycler the heating system is composed primarily of band heaters, solid state relays or SSRs that regulate higher voltage that is supplied to the heaters, thermistors which read the current temperature in each heating zone, and PID controls which take the temperature data and regulate the temperature by signaling the SSRs to activate or deactivate the heaters. More passive components are vital to this system as well however; the heating system directly integrates into the extrusion system, but between them the heating sleeve is designed to transfer heat evenly from the heaters into the barrel so that plastic melts consistently inside the barrel.

The heating system also includes a few components that ensure the melt area does not extend too high along the screw. This would complicate things by reducing the amount of ground plastic pushing other material forward. A series of heat sinks and fans are installed between the hopper feeding material into the barrel and the heating zones. These are actually cooling components, but are still directly involved in heat transfer and are included because of this. They function by drawing air in towards the barrel over heat sinks, that draw the heat from the barrel, and blowing that heated air up and out.

2.2.3 Extrusion system

The functional core of the MkI recycler is the extrusion system. Effectively this system comprises the components that touch shredded or molten plastic. These components are the hopper, the barrel, the screw inside it, and the hot end. Out of the list of components and parts used to build the recycler these components have required the most energy and attention to custom fabrication. In some cases just as much went into making custom jigs that could hold components in place during machining steps as went into the actual fabrication steps.

Figure 9 Close up of the hot-end in process brass right, and the heating sleeve copper left. Photo by Paul Nix.

The hopper is the clear exception, being 3Dprinted and designed to allow the use of a standard PET bottle. Currently it is using a .33cL bottle that has been cut in half and slightly reshaped by thermoforming under a heat-gun. It can be produced locally by makers who might want a different design, because it is located well above the melt-zone it should pose no problems.

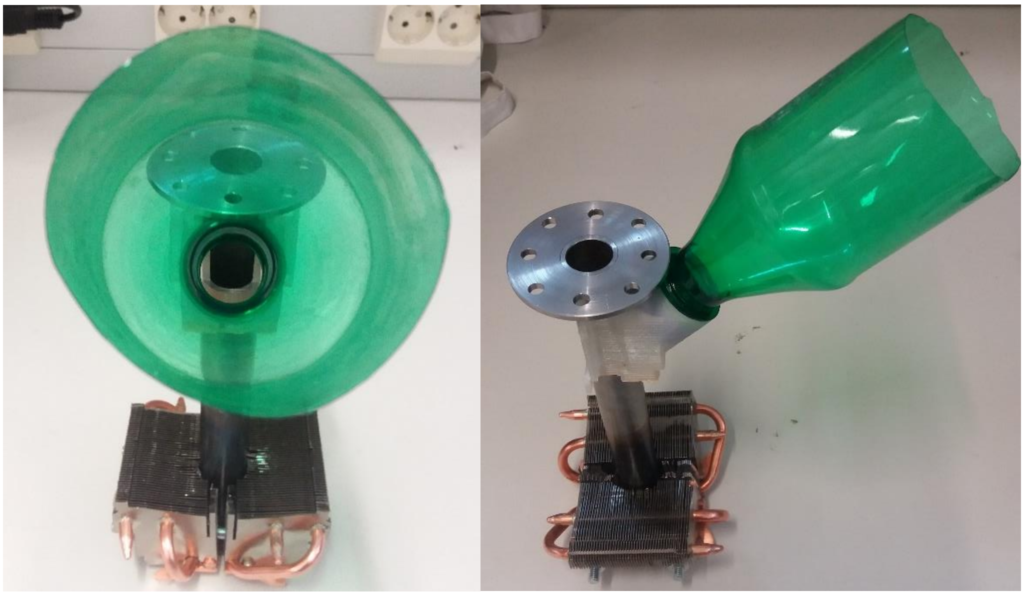

Figure 10 The hopper and the barrel, a view into the barrel left, profile of 3Dprinted hopper right. Photos by Paul Nix.

2.2.4 Frame Assembly

The frame assembly includes all the components meant to hold the recycler together. Primarily this means the aluminum x-profile extrusions that make up the visible bulk of the device. It also includes all of the 3Dprinted mounting boards for components such as the LCD display screen, the logic board, and the power supply. The 3Dprintable hammer-nuts designed by Jan-Peter Holm are easy to miss when examining the recycler. These nuts provide the tension connecting almost all of the frame components by slipping into the x-profiles and tightening down with standard machine bolts. They also cut the cost of assembling the device significantly as they could be 3Dprinted in bulk as needed, as opposed to being ordered by mail and made of steel.

Figure 11 3Dprinted fittings, hammer nuts top 2 and bottom, cable organizers middle left, brackets and hammer nuts middle right. Photos by Paul Nix.

2.2.5 Spooling System

The spooling system consists of an adjustable modular axle rod that can be loaded with spools of a variety of sizes, a stepper motor and gearbox which drive the axle to pull filament. A series of 3Dprinted brackets hold the spooling components in place and allow for customization based on the needs of different material blends. 3Dprinted centering cones fit onto the axle-rod to hold the spool on tight, and locking hand fittings provide a good grip to tighten down before screwing down tight to the axle. Some extruded materials may cool more quickly or slowly, some may have different material properties which require rapid customization. This is possible as the core components of this system can be reiterated and custom 3Dprinted.

3 METHODS

This thesis is not experimental in nature and because of this it does not rely on the collection of quantitative data. It instead relies on the qualitative analysis of information and the accumulated experience of the individuals involved in the process in order to propose conceptual changes which may result in many more data driven paper topics. In order to produce a valid and worthwhile plan for the MkII recycler, it was necessary to review all of the steps that went into the design of the MkI, as well as the process of building it and the final product.

3.1 Pre-thesis work

From the initial concept of a modular solution meant to combat waste accumulation, to the completed MkI recycler, much of the work preceding this thesis has led to specific ideas and analyses that have contributed to the thesis itself and the plan to move past it. Some of the ideation for the MkII came from the decisions that were made during the MkI that left alternative ideas in their wakes. All of the previous projects have contributed impressions of the value, requirements, and environment necessary for the MkII.

In order to put things into perspective it could be stated that the entire program at Arcada has been indirectly focused on this outcome. The program has had its focus on material and polymer science, mechanical engineering and fabrication techniques, as well as the study of sustainability and global problems. Some of the extracurricular and project based units, for example those centered around waste analysis with Ekochem (Fortum Waste Solutions Oy, 2018), and the repeated extrusion of recycled HDPE to gather data on properties changed by contamination, both projects led directly into this thesis by providing valuable insights that are only available when one spends hours and hours working at a topic. This is why so many of the preliminary projects are referenced.

Finally many contributions have come from conversations during the past five years, the acknowledgements will reflect several of the innumerable people who have contributed to this process by participating in conversation. Many disparate skillsets and backgrounds have contributed to the design process and eventual choices made during this thesis process.

3.2 Current work

This thesis began when the MkI was completed. At that point it became essential to begin outlining a report structure and confirm the possibility of writing a qualitative thesis. Once this was confirmed a review of previous work, an analysis of the MkI and a system by system list of changes that would be valuable for the MkII was necessary. Additionally it was necessary to look at the future of the project and its origins to place it in a bigger picture.

The majority of this thesis has been focused on the review of previous work, cataloguing of design iterations, and organization of ideas. Research into the specifics of competitors for the literature review was largely a review activity, revisiting the ideation process of the MkI design. Some of the redesigns for specific components required revision and work to clean up the designs in order to make them ready for the MkII, and others had been reiterated already and simply needed to be rotated or placed into assembly drawings to demonstrate how they would work in concert.

4 RESULTS

4.1 Improvements for MkII

The MkI recycler design is functional; however there is always room for streamlining. Below are listed specific, system by system upgrades and changes that will hopefully make the MkII smaller, more efficient, simpler to construct, and easier to operate. Ideally more changes to the MkII design and to later revisions of the recycler will come as more copies are constructed and shared online.

4.1.1 Logic system

The logic system has room for revision both physically and through its source code. The printed circuit board itself needs to be revised in order to allow access to the Teensy chips' USB interface, this could be accomplished by rotating it 180°. Doing this would require remaking the Eagle file used to route the circuitry around the board in order to accommodate this change. Alternately the components located directly above the teensy could be moved or replaced by low-profile equivalent parts. Currently the Teensy is on especially tall risers so that the USB interface is physically lifted over the blocking components.

The recycler additionally has room for IO inputs that can be used to integrate switches and push buttons that can be programmed to integrate the control of the heating system in order to make the system completely automatic. This could be done by rewiring the PID/heating circuits into the Teensy IO's and programming the device to turn on heat as soon as power is applied to the system and to regulate that heat along with the rest.

The 3Dprinted display backer board needs to be revised to allow the LCD screen to be mounted behind the board peeking through a display hole, additionally an access hole needs to be cut in the surface of the board to allow a small Philips screwdriver to adjust the screen brightness. All of the 3Dprinted backer boards could be further revised by making cuts and holes to reduce the material requirements of them without significantly decreasing their mechanical strength. Finally the power backer board is currently oversized, it needs to be revised so that it will fit onto a standard print bed. This can be accomplished by either breaking the current design into two halves which mechanically lock into one another, or by cleverly redesigning it. The redesign could start by reducing the length of the component so that the power supply was held in place by two screws instead of four, below is a comparison of how this first change would look:

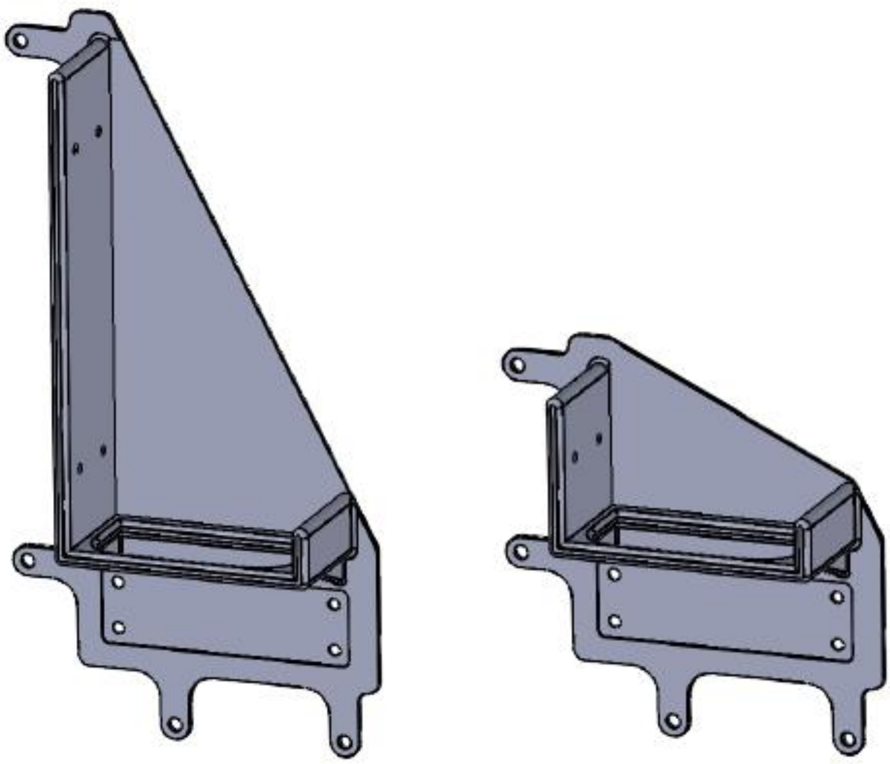

Figure 12 Comparison of the existing MkI power backer left, and the possible MkII power backer right. Design by Paul Nix.

This component was originally modelled to allow the face of the power supply to show through the window facing downwards, it could be further altered by opening the top of the window so that it allows the power supply to be installed fully wired or easily removed from its base to be rewired. This would greatly improve accessibility to the power supply without significantly reducing the strength of the power backer. If the strength of the component were to be reduced, this weakening could be offset by making ribs in the part below the sides of the opened window.

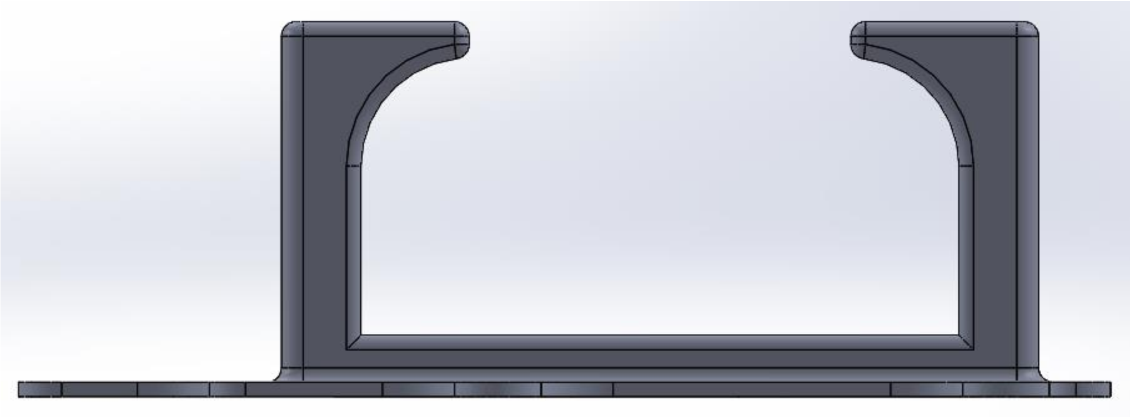

Figure 13 The MkII power backer seen from below with the proposed cut made. Design by Paul Nix.

4.1.2 Heating System

The heating system of the MkII recycler could be streamlined significantly. First as the barrel length is very short, the number of heating zones could be reduced to 1. In effect this means that the upper heating zone could be removed or both band heaters could be replaced by a single longer band heater. If a second heating zone were to be maintained all that would be required of it would be the thermistor to register the temperature at the top of the heating band. Below you can see both exploded views and transparent views of the updated heating system components. Note that while the barrel and thermistors remain much as they were in the MkI, the proposed update would bring the combined outer diameter of the heating sleeve to 42mm making it even with and flush to the outer diameters of both the lower barrel ring and the hot end. This allows for a larger and longer single heating sleeve to easily slide over the entire apparatus for even heat distribution both into the barrel and into the hot end which currently takes much more time to heat up in the MkI. It is also notable that the thermistor screw point on the hot-end has been moved from the outer edge to the underside of the hot-end. This enables much simpler assembly and disassembly for repair or maintenance.

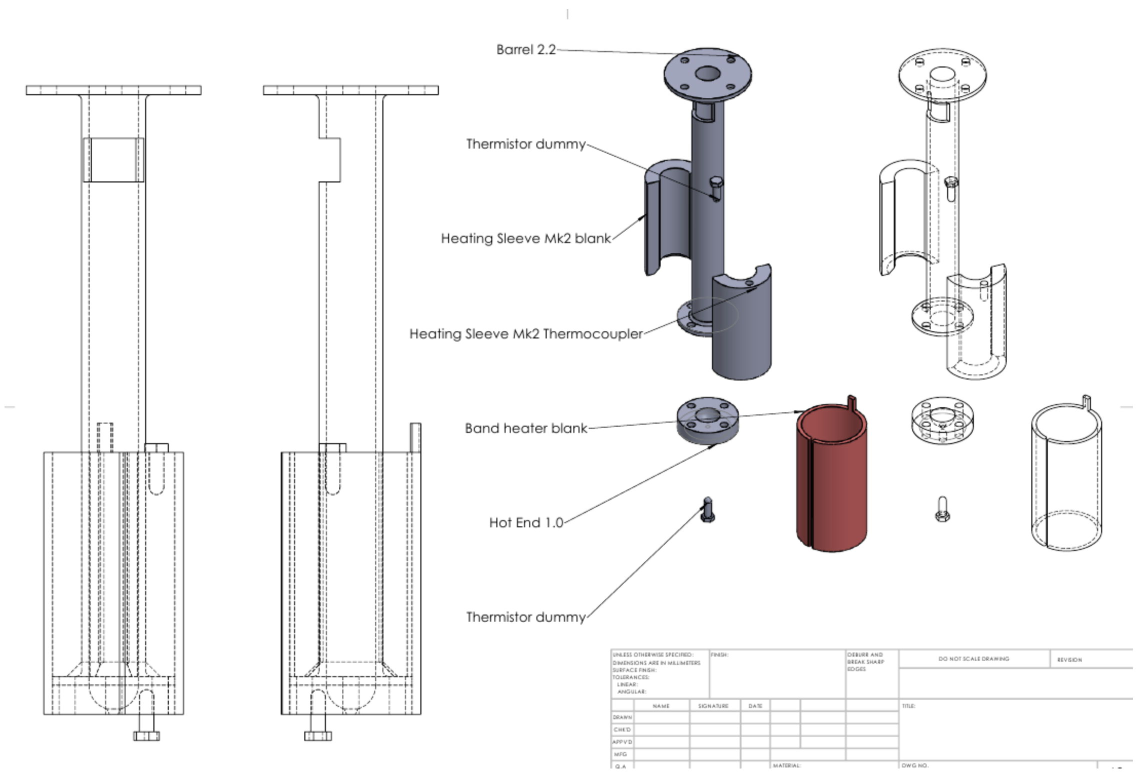

Figure 14 The MkII heating assembly. Design by Paul Nix.

Currently the cooling system in the MkI consists largely of found components. The idea behind this was that most makers and hobbyists will likely have access to old heat sinks that have come out of computers or power supplies, combining them with fans from similar sources allow an easy customization that can keep costs and custom fabrication costs down. Eventually it would be worthwhile to assemble a basic schematic and steps that could be used to adapt common parts and produce simple 3Dprinted components for attachment as has been done in the MkI.

4.1.3 Extrusion System

The extrusion system in the MkII system will be updated as well. First the barrel has already been updated from the initial design because the feed hole was not large enough, we opened the initial feed hole in the MkI barrel and updated the parts solidworks file. It may be that the feed hole will need to be further enlarged and or moved down slightly to provide a better angle for the hopper. The hopper itself should ideally be altered to give a minimum 45° slope feeding pellets into the barrel, this will allow a consistent flow of gravity-fed pellets to the screw which should draw material down the barrel. The MkII hopper can be 3Dprinted like the current model and will ideally retain the option of a modular attachment to a standard PET bottle as an extended hopper at either .33cL or 2L as desired.

As seen in the heating assembly diagram above the hot-end would be altered in the MkII by moving the threaded thermistor hole from the side of the disc to the bottom face. This allows the heating band to slip easily over the barrel sleeve and hot-end evenly, the thermistor is then screwed in from below. The new designs should also include several different disk designs for the hot-end so that different diameters of filament are available based on the needs of each facility, that way if they begin working with someone who uses a machine that requires a different filament width, they will be able to swap out the hot-ends while the machine is cold.

There is the possibility of refining the screw further to more clearly layout the compression zone, however this may not yet be necessary, it can likely wait for MkIII or later. There is another change that can be made to the barrel however, a gas vent can be installed along the melt zone to relieve pressure and prevent degradation of material. It is worth significant research as it might require a greater revision of both the screw and barrel to match the compression zone, melt zone, and metering zone if it is necessary.

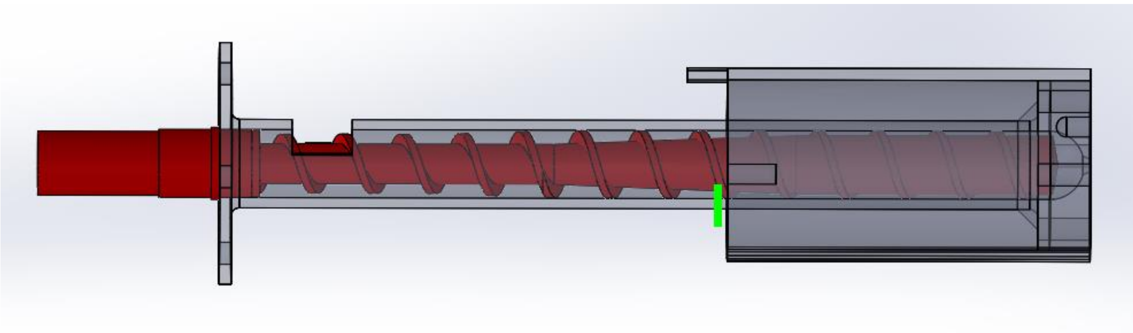

Figure 15 MkII extruder assembly with heating components, proposed vent location in green. Designs by Paul Nix and Jan-Peter Holm.

4.1.4 Frame Assembly

Changes to the 3DBear recycler in the MkII version will be both cosmetic and functional. First the aluminum x-profiles used in the MkI recycler can be replaced with significantly smaller extrusions.

Figure 16 A size comparison of different x-profiles. Photo HepcoMotion (HepcoMotion, 2018).

The 40x40 profiles used by the MkI can easily be replaced by 20x20's without compromising the strength of the frame, or function of the device. Additionally the overall footprint and size of the device can be reduced. There is currently significant negative space on the MkI device that can be removed from the design of the MkII reducing the volume by at least 1/3. The current x-profiles in the MkI recycler were also chosen for a degree of cosmetic value, each has two outer surfaces that are flat and without t-slots. The extrusions chosen for the MkII design will be completely modular in order to provide maximum potential utility, they will also have a lower price if they do not have to be cosmetically appealing like the current ones.

Figure 17 A close up of the frame extrusions from the MkI. Photo by Paul Nix.

4.1.5 Spooling System

The modular spooling system of the MkI recycler is extremely robust and should allow an incredible amount of customization and reconfiguration. The MkII will still be altered in order to bring the spool in line under the extruder, this is because all of our MkI extrusions using PLA have been cooling quickly enough that the default position of the spool can be close enough to facilitate immediate spooling.
In addition to this several of our design files for the spooling brackets will be made into easily modified blanks that will give users a quick starting point for customization. These files should be easy to alter whether users prefer solidworks, fusion360, or even tinkercad.

5 DISCUSSION

5.1 Next steps

Education allows all of us to interact with our immediate environments in ways we might not otherwise. Through our global data networks a person can learn about almost anything they would want to, we simply need to shift the focus through well publicized projects that capture general interest. Building the MkII recycler will inevitably lead to further iterations and design improvements on the current design; however by spreading the open-source design, 3DBear will ideally encourage a rapid concurrent iteration of improvements and the propagation of a strong infrastructure to support 3Dprinting. Through this extended project different facilities, makerspaces, and educational institutes will benefit from effective material use and the circular economy. This section will cover some of the specific next steps that are already being implemented in 2018.

5.1.1 Kauniainen Recycler Pilot

Currently 3DBear has entered into a pilot to produce a recycler in partnership with facilities in Kauniainen. This will mean a partnership in planning and design and will likely mean a device somewhere between a MkI and MkII. In any case a new recycler will be constructed that will generate more design ideas and better refine the process of construction from a 3rd party perspective. That way resources can be gathered that help the presentation of information on the web-site, and ideally the ease with which a new group could begin the building process.

While the details of this project have not yet been decided, the resulting device will allow for collaboration between material science students at Arcada and the students and staff at the location in Kauniainen where the new device will be housed. It will also allow for greater publicity for the project which will ideally boost interest and involvement in the project. While Kauniainen participates 3DBear will find ways to ensure that the construction process helps them to meet specific learning objectives for any students involved with the project and can develop curriculum that will provide even more value for any school that might want to participate.

5.1.2 Development of Recycler Webpage and Blog

As work on the recycler project continues past this thesis, changes and updates to the recycler will be documented and curated online. The 3DBear website should allow a forum for the discussion of design update ideas, it will continue to host open-source files, and pictures from different DIY and maker builds of the device. The work on the recycler has also led to a blog online in which I talk about different steps in the design process and the ideas and work behind the 3DBear recycler.

Jan-Peter will be taking part in the blog process as well by writing about engineering specifics from systems he has worked in the MkI device, detailed plans for MkII updates of specific components from the spooling system and optical sensor interface, and the active work involved with the ongoing Kauniainen build. While I will continue the blog with reflections on the journey we have taken and ties into the journey others may take if they decide to try their own build. Some of the planned entries I have in mind will be interviews of 3DBear staff involved with planning and supporting the project, perspectives from specialists and material scientists who will see all of the ways a device like this would need to improve to be relevant to a wider audience and more valuable to anyone involved, and interviews with people building their own devices in schools or maker spaces.

As the Kauniainen project begins it will give plenty of material that can be hosted immediately on the website and developed into blog entries, in the form of pictures, video, and feedback to update our existing materials. It should hopefully form a template of the kind of data and pictures that will be generated by any facilities taking up the project. Ideally it will continue to be of interest as people decide to start being more involved in ecological activities like recycling, cleanup, and the circular economy, with hobby activities like the maker movement, 3Dprinting, DIY, and educational activities like 3Ddesign, STEAM curriculum, and practical education.

5.1.3 Integration of External Developments into the MkIII Recycler

As new groups and users come up with innovations specific to the design of the recycler, new builds and components can be tested and approved into later total iterations of the project. That way we can keep not only a history of the development path but also a clear progression of new models that are ready to be produced by new facilities. This level of innovation and collaborative design is the core strength of the open-source model, and is at the heart of the success experienced by Linux, the open-source operating system, as well as by Prusa, one of the best 3Dprinter designs on the planet, and a host of others. With this sort of development environment many different facilities can collaborate and work simultaneously, sharing resources, successes, and most importantly failures. The users who are each taking skilled time and energy to contribute in projects like these are often working professionals taking hobby-time to dig away at the little puzzles that they enjoy and communicating through forums so that others benefit from their iterations. By streamlining the process by which changes to parts can be reviewed and integrated into a design, and by involving more people, labs, and build-testing resources, the entire community will contribute value to the project while reaping compound benefits.

5.1.4 Direct Comparative Testing of Different Builds/Blends

Perhaps the most important aspect of this collaborative environment is that different facilities will be able to start experimenting with more than just new recycler designs, but also with new material blends. PLA will be the most common starting point but as schools begin having students collect old laundry bottles made from HDPE and PET soda bottles and other kinds of plastics they will start cleaning and shredding them to try recycling these too. They, and the greater project community, will learn as they make mistakes; for example, it is likely that many people will have shreds of different plastics like PET and nylon that absorb water from the atmosphere, once they get inconsistent filament results they will start to discuss online and learn that by drying the material before extruding it they can prevent this problem. They will learn which materials work best at which temperatures, and other ways of optimizing their extrusion speeds for example, to get the most out of any material they may want to work with. Soon ideal blends and best practices will begin developing simultaneously in labs around the world, the same way new software codes and DIY projects get written.

The testing is not limited to the level of layman, because these devices will likely be built at least in part in educational institutions testing can be not only very specific, but also very detailed. A facility that specializes in testing material properties and tensile strength like Arcada would be able to coordinate with facilities that specialize in chemical testing to get detailed information about food safety or long term chemical release from different blends. By collaborating and exchanging samples and data at this level not only would resources be pooled and conserved but research at a high level could benefit, and these institutes could help with the development of resources to help guide hobbyists and lower level institutions through polymer science. In fact the number of sub-projects and thesis works at multiple levels that could be generated by a modular build project like this are incalculable. By involving vastly more people in the practical aspects of material science, fields like polymer identification and recycling will become better understood by common individuals and governments. It is my hope that this will be the greatest value of the open-source recycler project. A world in which people don’t have to wonder “What can be done” with plastic waste.

6 CONCLUSION

While the MkII has not yet been built, the proposed changes in its design over the MkI recycler should provide significant benefits. Not only should the MkII be simpler to build, and be less expensive, it should be more modular and produce a better quality product. It is meant to remain open-source, the updated design should improve involvement by bringing in more groups to build copies and contribute revisions.

Because of the qualitative nature of this thesis there is no measurable result. It is however clear that the proposed changes will result in marked improvements. The changes should simplify construction, operation, and further revision, for anyone interested in the project. Continuation of this project through open-source builds and remixes of the MkII will result in accelerated changes to the 3Dprinter ecology that exists in many regions. While it is unclear how noticeable this change will be, the scale of our global issues give us remarkable room to grow and show improvement.

This project and in particular the MkII design fits the initially proposed criteria of a scalable, safe, simple, open-source, modular solution that was considered at the beginning of the Bali ecological project. It has remained the guideline for successive projects, and is demonstrated throughout the design of the MkII. Such a solution should provide a template for the kind of change that would be required to address globally scaled problems, systematically, by addressing their causes and the way we look at resources.

Figure 18 Plastic in CorCups, mixed PLA shred and virgin PLA at the top, and three mixes % of virgin material added into shred by weight at bottom. Photo by Paul Nix.

FIGURES

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I could not have asked for a better partner in building the MkI than Janne. Please know that your technical brilliance and broad knowledge are only two of a million ways you made my life easier during the projects I have been fortunate enough to share with you.

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Arcada University of Applied Sciences

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3DBear

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“God only knows what I'd be without you.”
-The Beach Boys, God only knows

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